

# **Supplemental Analysis to Support Postulated Events in the Process Hazards Analysis for the HEAF**

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## **1.0 Purpose of the Report**

The purpose of this report is to conduct a limit scope risk assessment by generating event trees for the accident scenarios described in table 4-2 of the HEAF SAR, ref 1. Table 4-2 lists the postulated event/scenario descriptions for non-industrial hazards for HEAF. The event tree analysis decomposes accident scenarios into basic causes that appear as branches on the event tree. Bold downward branches indicate paths leading to the accident. The basic causes include conditions, failure of administrative controls (procedural or human error events) or failure of engineered controls (hardware, software or equipment failure) that singly or in combination can cause an accident to occur. Event tree analysis is useful since it can display the minimum number of events to cause an accident. Event trees can address statistical dependency of events such as a sequence of human error events conducted by the same operator. In this case, dependent probabilities are used. Probabilities/frequencies are assigned to each branch. Another example of dependency would be when the same software is used to conduct separate actions such as activating a hard and soft crow bar for grounding detonator circuits. Generally, the first event considered in the event tree describes the annual frequency at which a specific operation is conducted and probabilities are assigned to the remaining branches. An exception may be when the first event represents a condition, then a probability is used to indicate the percentage of time the condition exists. The annual probability (frequency) of the end state leading to the accident scenario in the event tree is obtained by multiplying the branch probabilities together.

## **2.0 Conduct of the study**

To conduct the study, it was important to know the hazards associated with explosives operations that include handling, processing, synthesis, transporting, storage and testing. Firing tank operations were examined in detail. A block diagram of the firing circuit (see figure 1) was generated to facilitate the understanding of how the major system components work in the shot sequence for the firing tanks. A similar scheme is used at site 300.

### **2.1 HEAF tours**

Numerous tours of HEAF were taken. The following important components were observed in the control rooms for the firing tanks:

1. System key
2. HE key
3. Green button for start
4. Red button for fire
5. Red button for stop
6. White button for reset
7. Computer displays

The following components were examined for the run/safe system:

1. Access Entry Box
2. Run/Safe box
3. Micro Switch Door
4. Beacon
5. Door Exit box
6. Sweep box

The following components were examined for the firing tanks:

1. Tank ports
2. Ventilation system
3. Tank door and switches
4. Hydraulic system to open/close door
5. Soft crow bar (bleeder resistor)
6. Hard crow bar
7. Detonator grounding panel

and the tank diagnostic equipment that included:

1. High Speed Cameras
2. Flash Lamps
3. Laser Doppler Interferometer
4. Laser illumination and imaging
5. Heating of explosives
6. e-gun
7. X-ray heads

Numerous chemical laboratories were examined and the following were observed:

1. Fume hood ventilation system
2. Room ventilation
3. Acid Waste collection system
4. Posted weight limits and inventory
5. Storage repositories

The walls, blast doors, mazes and loading dock to HEAF were observed.  
Containers used for movement of HE were observed --

1. ammunition cans
2. ice cream cartons
3. push carts

Small scale testing components were observed

1. Drop hammer machine
2. Spark test machine
3. Friction test machine

and ODTX components that include:

1. heaters
2. holding fixtures
3. test instrumentation circuitry
4. two remote cells with shielded windows
5. shock absorbing material.

The drawers, cubicles and DOT containers were observed in magazine storage. The personal duress system was examined; specific components include

1. Transmitters
2. Receivers
3. Alarm Strobes
4. Directional Alarm Strobes
5. Alarm Horns (entrance to each room)
6. Map Display Panel
7. Annunciator Panel
8. Control Chassis & Power Distribution.

## **2.2 HEAF Personnel Discussions**

Discussions with the following individuals occurred:

William Gilliam (Facility Manager)  
Roanne Lee (Lead Mechanical Engineer)  
Greg Mack (Lead Electronics Engineer)  
Jim Dotts (Explosives Safety Engineer)  
Denise Grimsley (1 Kg Tank Operator)  
Gary Steinhour (Electronics Technician)  
Ernie Urquidez (Gun Tank Operator)  
Don Burns (Electronics Technician)  
David Hill (Explosives Safety Engineer)  
Mike Tandy (Materials Management)  
Jon Maienshein (Energetic Materials Section Leader)

## **2.3 Documents Reviewed**

The following documents were reviewed:

1. The ES&H manual ref. 2

2. The HEAF facility safety plan (FSP), ref. 3
3. Numerous HEAF control documents regarding explosives storage, operations, hazards analysis

Of particular importance to the risk assessment were two sections of the FSP -- chapter 5 (entitled Hazards Analysis and Controls) and appendix C (entitled Safety Plans for Specific Operations) and the operational procedures that were referenced for these two sections.

### 3.0 Risk Assessment

Simple event trees were constructed for each hazard scenario in the HEAF SAR to help in the qualitative assessment of event occurrence probabilities. Appendix A contains these event trees. Each event in an event tree was classified into one of the probability categories shown in Table 1.

Table 1 Probability rating levels

Category	Description	Estimated occurrence rate per year (nominal or best estimate)
Less than credible	Events are expected not to occur during the life cycle of the facility.	$10^{-6}$
Extremely unlikely	Events will probably not occur during the life cycle of the facility.	$10^{-4}$
Unlikely	Events may occur once during the life cycle of the facility.	$10^{-2}$
Medium	Event may occur during the facility or operation lifetime	$10^{-1}$
Likely	Events may occur several times during the life cycle of the facility.	1
Very likely	Events may often occur.	100

The frequency at which operations are conducted was obtained from ref. 4. The probability of each event tree branch was estimated by examining pairs of events and estimating the probability of event pairs as shown in Table 2. Where more than two events make up an event tree branch the branch probability was estimated by examining pairs of events, treating a pair as a single event and re-entering Table 2.

The probability of a hazard scenario was taken as the probability of the most likely branch in the associated event tree. No attempt was made to sum probabilities over all branches as the trees contain relatively few branches. Summing over branches in a quantitative probability estimation scheme would affect the probability estimates by a factor of 3 to 5. Such changes are below the resolution of the qualitative scheme adopted here.

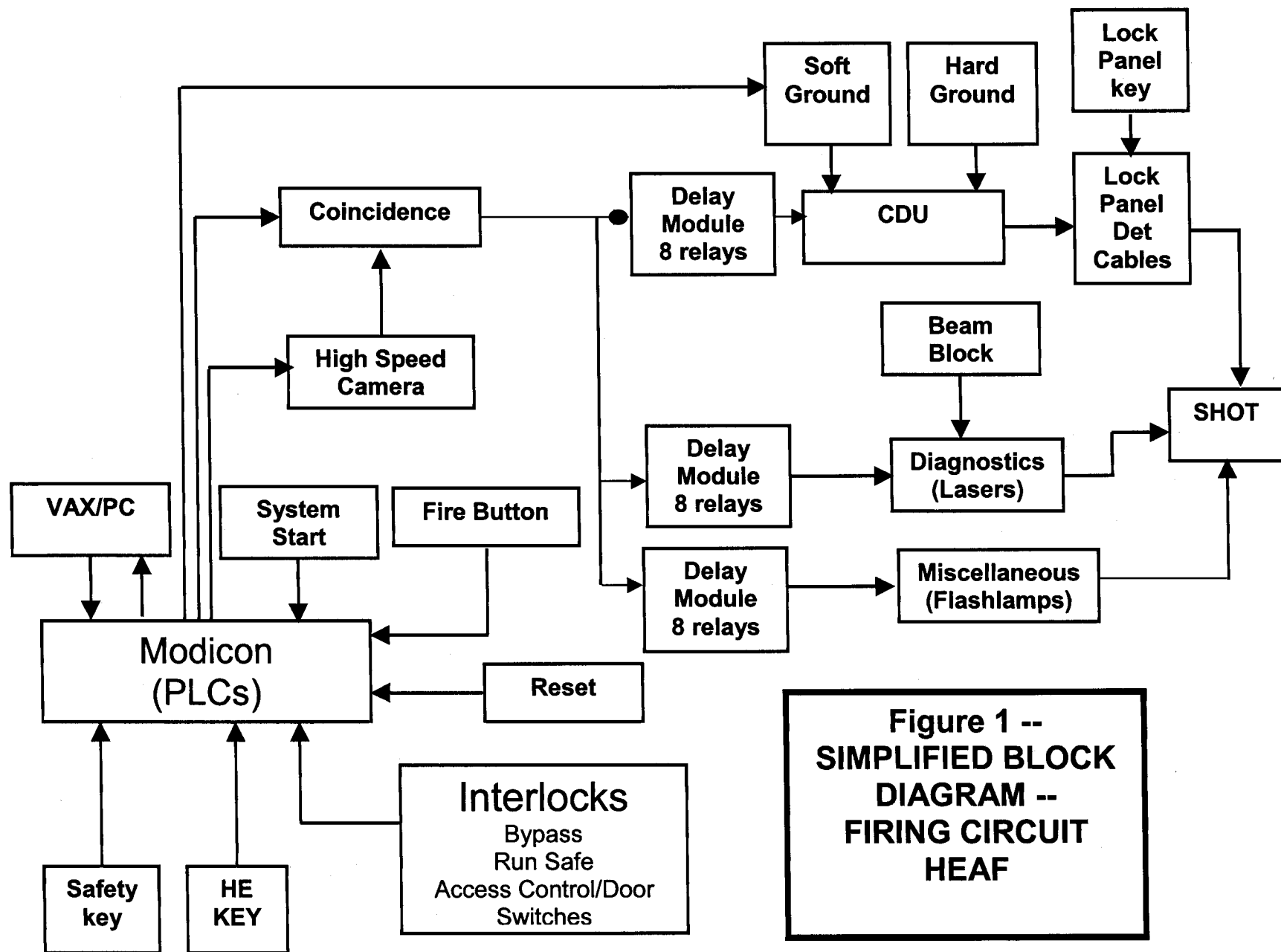
The probability estimates of this analysis are used in the HEAF SAR summary hazard tables and together with the estimated consequences form the basis for deciding risk acceptability.

Table 2 -- Joint Probability Table (combining the probability of two events)

Annual Frequency Or Probability	→	$1.0 \times 10^{-6}$	$1.0 \times 10^{-4}$	$1.0 \times 10^{-2}$	0.1	1	100
↓	Relative Probability Description	Less than credible	Extremely Unlikely	Unlikely	Medium	Likely	Very Unlikely
$1.0 \times 10^{-6}$	Less than credible	Less than credible	Less than credible	Less than credible	Less than credible	Less than credible	Extremely Unlikely
$1.0 \times 10^{-4}$	Extremely Unlikely	Less than credible	Less than credible	Less than credible	Extremely Unlikely	Extremely Unlikely	Unlikely
$1.0 \times 10^{-2}$	Unlikely	Less than credible	Less than credible	Extremely Unlikely	Unlikely	Unlikely	Likely
0.1	Medium	Less than credible	Extremely Unlikely	Unlikely	Unlikely	Medium	Very Likely
1	Likely	Less than credible	Extremely Unlikely	Unlikely	Medium	Likely	Very Likely
100	Very likely	Extremely Unlikely	Unlikely	Likely	Very likely	Very likely	Not applicable

#### 4.0 References

1. High Explosives Applications Facility (HEAF), Building 191, Revised July 2001, Safety Analysis Report, Lawrence Livermore National Laboratory.
2. ES&H Manual, Lawrence Livermore National Laboratory, Part 3.1.
3. Facility Safety Plan, High Explosives Applications Facility, Building 191, FSP-191, Effective September 30, 2000.
4. Memo from Carl Ingram to Howard Lambert, entitled "Estimated Activity Levels in HEAF, July 18, 2001.



**Figure 1 --  
SIMPLIFIED BLOCK  
DIAGRAM --  
FIRING CIRCUIT  
HEAF**



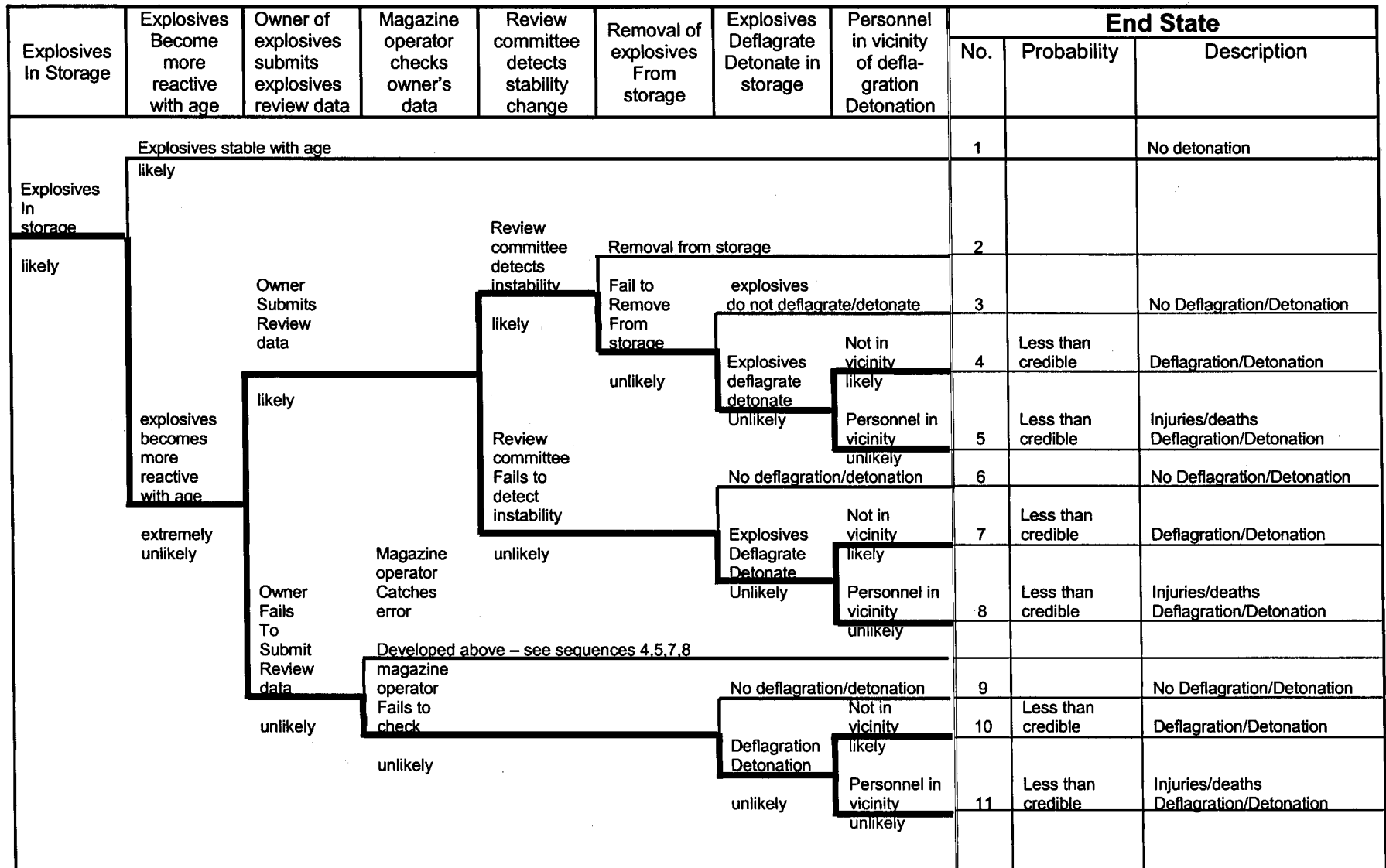
# **APPENDIX A**

## **EVENT TREES**

**Fig A -- SAR Scenario A. Accidental Detonation or Deflagration of Explosives:** Explosives are dropped or struck during handling or processing (either transport or class II operations such as assembly)

Explosives are being transported, processed or assembled	Explosives are struck or dropped	Type of explosives handled	HE is restrained, packaged or shielded	Impact energy sufficient to cause detonation	End State		
					No.	Probability	Description
Explosives are being transported processed or assembled  Very likely	HE not struck or not dropped				1		
	Explosives are struck or dropped  unlikely	Insensitive explosives are being handled  likely	HE is restrained packaged or shielded	Insufficient energy to cause detonation	2		No detonation
			likely	Sufficient energy to cause detonation Less than credible	3	Extremely unlikely	Detonation Injuries or deaths
			Bare HE handled	Insufficient energy to cause detonation	4		
				Sufficient energy to cause detonation Extremely unlikely	5	Extremely unlikely	Detonation Injuries or deaths
		Sensitive explosives are being handled  unlikely	HE is restrained packaged or shielded	Insufficient energy to cause detonation	6		
			likely	Sufficient energy to cause detonation Extremely unlikely	7	Extremely unlikely	Detonation Injuries or deaths
			Bare HE handled	Insufficient energy to cause detonation	8		
				likely	Sufficient energy to cause detonation	9	Extremely unlikely

Fig B – SAR Scenario B -- Accidental Detonation or Deflagration of Explosives in storage



**Fig C – SAR Scenario C -- Accidental Detonation Or Deflagration Of Explosives -- Intentional Detonation Experiment Prematurely Fires With Personnel In Tank Room And Tank Open**

Personnel are setting up experiment with HE in firing tank	Grounding			CDU Charged and Fired while detonators cables are being hooked up to HE	End State		
	Detonator Cables (Administrative Control)	Hard Crow Bar (Administrative Control)	Soft Crow Bar Bleeder Resistor (Administrative Control)		No.	Annual Probability	Description
Personnel are setting up experiment in firing tank  Very likely	Detonators grounded				1		NO DETONATION
	Hard crow bar installed and working properly				2		NO DETONATION
	Detonators not grounded -- administrative error  unlikely	Hard crow bar not installed -- administrative error			3		NO DETONATION
		Hard crow bar not installed -- administrative error  medium (dependent probability)	Soft crow bar not installed -- Administrative error		4		NO DETONATION
			CDU not charged likely		5	extremely unlikely	DETONATION – MULTIPLE INJURIES OR DEATH
			CDU charged and fired – software failure  extremely unlikely				

D. Accidental detonation or deflagration of explosives: explosives are initiated by electrical energy from adjacent equipment or utilities

Personnel setting up experiment	Component involved in event	Power source	Equipment inherent safety	Amount of energy applied	Personnel shielded when detonation occurs	End State		
						No.	Probability	Description
Personnel setting up experiment Very Likely	Detonator	Utility power applied to component		Insufficient energy applied to cause detonation or deflagration		1		NO DETONATION
		Extremely Unlikely		Sufficient energy applied to cause detonation or deflagration		2	Extremely unlikely	DETONATION DEATH / INJURY
		Power applied from portable equipment applied to component	Equipment review and approval ensured inherent safety	Unlikely		3		NO DETONATION
		Unlikely	Equipment review allows unsafe equipment	Insufficient energy applied to cause detonation or deflagration		4		
			Unlikely	Sufficient energy applied to cause detonation or deflagration		5	Extremely unlikely	DETONATION DEATH / INJURY
				Unlikely				
		Meter power applied to component	Equipment review and approval ensured inherent safety			6		NO DETONATION
		Likely	Equipment review allows unsafe equipment	Insufficient energy applied to cause detonation or deflagration		7		NO DETONATION
			Unlikely	Sufficient energy applied to cause detonation or deflagration	Personnel protected	8		NO DETONATION
See next page for HE case				Unlikely	Personnel exposed to detonation	9	Extremely unlikely	DETONATION DEATH / INJURY
					Unlikely			

D. Accidental detonation or deflagration of explosives: explosives are initiated by electrical energy from adjacent equipment or utilities

Personnel setting up experiment	Component involved in event	Power source	Equipment inherent safety	Amount of energy applied	Personnel shielded when detonation occurs	End State		
						No.	Probability	Description
From previous page	High Explosive	Utility power applied to component		Insufficient energy applied to cause detonation or deflagration		10		NO DETONATION
		Extremely Unlikely		Sufficient energy applied to cause detonation or deflagration		11	Extremely unlikely	DETONATION DEATH / INJURY
				Extremely unlikely				
		Power applied from portable equipment applied to component	Equipment review and approval ensured inherent safety			12		NO DETONATION
		Unlikely	Equipment review allows unsafe equipment	Insufficient energy applied to cause detonation or deflagration		13		NO DETONATION
			Unlikely	Sufficient energy applied to cause detonation or deflagration		14	Extremely unlikely	DETONATION DEATH / INJURY
				Unlikely				
		Meter power applied to component	Equipment review and approval ensured inherent safety			15		NO DETONATION
		Unlikely	Equipment review allows unsafe equipment	Insufficient energy applied to cause detonation or deflagration		16		NO DETONATION
			Unlikely	Sufficient energy applied to cause detonation or deflagration		17	Less than credible	DETONATION DEATH / INJURY
				Extremely Unlikely				

**Fig E– SAR Scenario E** Accidental Detonation or Deflagration of Explosives: Explosives are initiated by electrical energy from electronic gun

Personnel are setting up experiment with electronic gun in firing tank	Grounding			CDU Charged and Fired while electronic gun is being hooked up	End State		
	CDU Cables (Administrative Control)	Hard Crow Bar (Software Control)	Soft Crow Bar Bleeder Resistor (SoftwareControl)		No.	Annual Probability	Description
Personnel are setting up experiment in firing tank	CDU grounded				1		NO DETONATION
		Hard crow bar closed and working properly			2		NO DETONATION
	CDU not grounded -- administrative error		Soft crow bar closed and working properly		3		NO DETONATION
	unlikely	Hard crow bar Open -- Software error			4		NO DETONATION
		unlikely	Soft crow bar Open -- Software error		5	extremely unlikely	DETONATION – MULTIPLE INJURIES OR DEATH
Very likely				CDU not charged likely			
				CDU charged and fired -- software failure			
				Unlikely (dependent probability)			

**Fig F -- SAR Scenario F. Accidental Detonation or Deflagration of Explosives: Explosives are initiated by nearby fire**

IGNITION SOURCE AVAILABLE	HOUSE KEEPING PRACTICES	FIRE OCCURS AND NEAR EXPLOSIVES	EXTINGUISH- MENT BEFORE EXPLOSIVES INVOLVEMENT	SUFFICIENT HEAT TO CAUSE DETONATION	EVACUATION BERFORE DETONATION	End State		
						No.	Annual Probability	Description
Ignition Source Available For example Welding  very likely	Good House Keeping Practices – no combustibles or flammables nearby					1		
	Poor Housekeeping Practices -- Storage of Flammables Or combustibles  unlikely	Fire not nearby				2		
		Fire extinguished in time				3		
		Insufficient Heat to cause detonation				4		
		Fire nearby  unlikely	Evacuation Before detonation		likely	5	extremely unlikely	detonation
			Can not Evacuate In time		unlikely	6	Less than credible	Detonation Injuries/ deaths



**Fig G. SAR Scenario G** Accidental detonation or deflagration of explosives: explosives are initiated by chemical reaction occurring nearby

Chemical processing near HE	Chemical compatibility	Peer review detects compatibility issue	Incompatible chemicals violently react	Reaction of incompatible chemicals detonates HE	Personnel shielded when detonation occurs	End State				
						No.	Probability	Description		
Chemical processing near HE	Chemicals are compatible or compatibility issues are adequately addressed					1		NO DETONATION		
	Hazards of incompatible chemicals not adequately addressed	Compatlbility issues are adequately addressed				2		NO DETONATION		
		Peer Review Fails to Detect incompatibility	Violent reaction does not occur			3		NO DETONATION		
			Unlikely	Reaction does not cause HE detonation or deflagration			4	Extremely Unlikely	VIOLENT CHEMICAL REACTION INJURY	
				Unlikely	Violent chemical reaction		Personnel not exposed To detonation	5	Less Than Credible	DETONATION
					Unlikely To Extremely unlikely	Reaction causes HE detonation or deflagration		Likely		
	Very likely			Unlikely	Personnel exposed to detonation	6	Less Than Credible	DETONATION INJURY / DEATH		
				medium						

**Fig. H. – SAR SCENARIO H –** Accidental detonation or deflagration of explosives: explosives are initiated or sensitized and initiated by normal handling by reaction from chemical incompatibility

Personnel setting up experiment	Chemical exposure to HE	Experiment uses new chemical	Chemical Compatibility	Peer review detects incompatibility	Testing detects incompatibility	Detonation occurs	End State			
							No.	Probability	Description	
Personnel setting up experiment	HE not exposed to chemicals						1		NO DETONATION	
	HE exposed to chemicals	Experiment does not use new chemical	Chemical compatible						NO DETONATION	
			Incompatibility addressed						NO DETONATION	
			Chemical incompatible	Review does not detect incompatibility		Detonation Does not occur	3		NO DETONATION	
				Unlikely	Unlikely	Detonation occurs unlikely	4	Extremely unlikely	DETONATION INJURY/ DEATH	
		Chemical compatible				5		NO DETONATION		
		Incompatibility addressed				6		NO DETONATION		
		Experiment use new chemical	Chemical incompatible	Review does not detect incompatibility		Incompatibility addressed	7		NO DETONATION	
				Medium	Unlikely	Testing does not detect incompatibility	Detonation Does not occur	8		NO DETONATION
			Medium			Medium	Detonation occurs unlikely	9	Less Than credible	DETONATION INJURY/ DEATH

**Fig I– SAR Scenario I --** Accidental Detonation or Deflagration of Explosives: Explosives are initiated by heating from laser

OPERATIONS INVOLVING USE OF HIGH POWERED LASER	OPERATIONS INVOLVING USE OF HIGH POWERED LASER	Laser shutter position	HE DETONATES DUE TO OVERTEMPERATUE	End State		
				No.	Probability	Description
Operations involving the use of high powered lasers	Control Circuit Works			1		No detonation
		Laser Shutter remains closed		2		No detonation
	Power control circuit For laser fails full on Software failure		HE does not detonate	3		No detonation
Very likely	Extremely unlikely	Laser shutter inadvertently opens – Independent software failure				
			HE overheats And detonates	4	Less Than credible	Detonation/ Injuries or Deaths
		Extremely Unlikely	unlikely			

**Fig J. SAR scenario J--** Accidental detonation or deflagration of explosives: Explosives are initiated from normal stimuli after synthesis of unusually sensitive intermediate (or final) product.

Personnel setting up experiment	Synthesis operation produces unstable intermediate or final products	Peer Review recognizes that chemical reaction products are unstable	Hazard characterization for scale up tests detect sensitivity	HE detonates during normal handling	End State		
					No.	Probability	Description
Personnel Are Setting up experiment	No unstable intermediate or final products produced				1		No detonation
	Peer review detects problem with synthesis operation				2		No detonation
	Hazard characterization tests detect sensitivity				3		No detonation
	Detonation does Not occur during Normal handling				4		No detonation
	Detonation occurs During Normal handling				5	Less Than credilbe	Detonation Injuries or deaths
Very likely	unlikely	unlikely	Extremely unlikely	likely			

**Fig K – SAR Scenario K. Accidental Detonation or Deflagration of Explosives:** Explosives are initiated by unintentional heating to critical temperature.

OPERATIONS INVOLVING HE HEATING	POWER CONTROL CIRCUIT STATUS	OPERATOR OSERVES TEMPERATURE	REDUNDANT TEMPERATURE MONITORING	SHIELDING PROTECTS PERSONNEL	End State		
					No.	Annual Probability	Description
Operations involving HE heating	Control circuits work				1		NO DETONATION
	Operator observes high temperature				2		NO DETONATION
	Redundant temperature shutdown works				3		NO DETONATION
	Power Control for heating HE fails ON	Operator fails to observe high temperature	Redundant Temperature Control fails to turn Off heater	Detonation occurs and shields personnel	4		Detonation
	unlikely	unlikely	unlikely	Personnel Are not shielded From detonation	5	Less Than credible	Detonation Injuries deaths
Very likely				unlikely			

**Fig L. SAR Scenario L -- Intentional detonation: Firing tank is breached or 100 mm gun breach fails**

Firing Tank Operation	Special Conditions – Safety Limits are Approached	Setup Experiment Correctly	Check list examination	Tank or Gun Breached – safety factors exceeded	End State		
					No.	Annual Probability	Description
Firing Tank Operation	No special conditions				1		Tank or Gun not Breached
	Experiment set up correctly				2		Tank or Gun not Breached
	Special Conditions – Safety Limits Are approached  medium	Checklist examination detects error			3		Tank or Gun not Breached
		Experiment setup Incorrectly – e.g., Limits exceeded, Shielding not used, Incorrect placement Of explosive in tank  unlikely	Tank or Gun Breached – Safety factors not exceeded		4		Tank or Gun not Breached
			Checklist examination Fails to Catch error				
		Medium (dependent Probability)		Tank or Gun Breached -- Safety factors exceeded  unlikely	5	Extremely unlikely	Tank or gun breached

Fig. M SAR Scenario M -- Chemical dispersion/release

OPERATIONS ARE OCCURRING IN CHEMICAL LABORATORIES	INIATING EVENT THAT COULD CAUSE HAZARDOUS CHEMICAL RELEASE IN CHEMICAL LABORATORIES	HOOD/VENTILATION SYSTEM MITIGATES CHEMICAL RELEASE	No.	AnnualIP Probability	Description
Operations Are occurring In Chemical laboratories  likely	Exothermic Chemical Reaction Due to human error  unlikely (see event tree G)	Hood ventilation System mitigates Chemical release	1		
		Hood ventilation System fails to mitigate Chemical release	2	Extremely unlikely	Hazardous chemical release
	Leak or Spill Of container  unlikely	unlikely  Hood ventilation System mitigates Chemical release	3		
		Hood ventilation System fails to mitigate Chemical release	4	Extremely unlikely	Hazardous chemical release
	Fire In Proximity Of chemicals  unlikely (see scenario F)	unlikely  Hood ventilation System mitigates Chemical release	5		
		Hood ventilation System fails to mitigate Chemical release	6	Extremely unlikely	Hazardous chemical release
	chemicals In proximity To accidental Explosives Initiation  Extremely unlikely (see scenario A)	unlikely  Hood ventilation System mitigates Chemical release	7		
		Hood ventilation System fails to mitigate Chemical release	8	Extremely unlikely	Hazardous chemical release
		likely			

**Fig N-- SAR Scenario N. Radiological dispersion/release: Radiological materials are dispersed due to combination of spill and fire.**

DIAMOND ANVIL OR EXPANDING RING OPERATION	IGNITION SOURCE AVAILABLE	HOUSE KEEPING PRACTICES	FIRE OCCURS AND NEAR OPERATION	EXTINGUISHMENT BEFORE INVOLVEMENT	SUFFICIENT HEAT TO CAUSE SPILL AND RELEASE	End State		
						No.	Annual Probability	Description
Diamond Anvil Or Expanding Ring Operation occurring	No Ignition source					1		
	Ignition Source Available For example Welding	Good House Keeping Practices – no combustibles or flammables nearby				2		
		Poor Housekeeping Practices -- Storage of Flammables Or combustibles	Fire not near operation			3		
			Fire Near Operation	Fire extinguished in time		4		
				Insufficient Heat produced	Sufficient Heat Generated To Cause spill And release	5		
						6	Less than credible	Small radiological release
very likely	unlikely	unlikely	unlikely	medium	medium			



**Fig O -- SAR Scenario O -- Chemical exposure:** Personnel are exposed to toxic or asphyxiant gases or radiological contamination from re-entry into firing tanks after an experiment

FIRING TANK OPERATION	OPERATES VENTS TANK	OPERATOR PURGES TANK	SOFTWARE PREVENTS OPENING TANK DOOR	OPERATOR FAILS TO OBSERVE TANK TEMPERATURE AND OPENS DOOR	End State		
					No.	Annual Probability	
Firing Tank Operation	Tank Vented				1		No significant exposure
	Tank purged				2		No significant exposure
	Tank not vented	Software prevents tank door opening			3		No significant exposure
		Tank not purged	Operator Observes high Tank temperature Does not open door		4		No significant exposure
	unlikely		Software Fails To Prevent Door opening		5	Less Than credible	potential significant exposure
	Very likely	High (dependent Probability)					

**Fig P -- SAR Scenario P -- Ionizing radiation exposure: Personnel are exposed to radiation from radiation generating devices (e.g. x-ray heads)**

Radiation Generating Devices are used in an experiment	Inadvertent firing of device	Personnel in line of device when firing occurs	End State		
			No.	Annual Probability	Description
Radiation Generating Devices Are used in an experiment Such as X-ray heads	Radiation device functions as intended		1		Personnel are not exposed
	Personnel not exposed		2		Personnel are not exposed
	Radiation Device Inadvertently Fires due to Software failure	Personnel exposed	3	Extremely unlikely	Personnel exposed To radiation
		unlikely			
Very likely	Extremely unlikely				

**Fig Q – SAR Scenario Q -- Non-ionizing radiation exposure: Personnel are injured from exposure to laser light**

Laser producing devices used in an experiment	Inadvertent firing of a laser	Personnel using safety goggles	Personnel exposed to laser light	End State		
				No.	Annual Probability	Description
Laser producing Devices Used in an experiment	Laser functions as intended			1		No injuries
	Inadvertent Firing of A laser Due to Software failure	Personnel not in line of Sight of laser		2		No injuries
		Personnel uses Safety goggles	Personnel in line of Sight of laser	3	unlikely	Possible laser burns
			medium			
		Personnel fail To use safety goggles	Personnel not in line of Sight of laser	4		No injures
			Unlikely	Personnel in line of Sight of laser		Extremely unlikely
Very likely	Extremely unlikely		medium			

**Fig. S – Scenario S -- Personnel exposed to overpressure: Secondary burnoff in firing tank ruptures exhaust ventilation ducting.**

FIRING TANK OPERATION	EXCESSIVE COMBUSTIBLES USED	SOFTWARE PREVENTS VENT VALVE OPENING	OPERATOR OPENS VENT VALVE BEFORE TANK COOL DOWN	PERSONNEL EXPOSED TO OVERPRESSURE	End State				
					No.	Probability	Description		
FIRING TANK OPERATION	Excessive combustibles not used				1		No exposure		
	Software Prevents Vent valve From opening				2		No exposure		
					3		No exposure		
	Excessive combustibles used	Operator waits to open vent valve After tank cool down				4		No exposure	
		unlikely	Software Fails To prevent Vent Valve opening				5		No exposure
			Extremely unlikely	Operator opens Vent valve Before Tank cool down				6	
Very likely	unlikely				7		No exposure		
	unlikely				8		No exposure		
				9		No exposure			
				10		No exposure			
				11		No exposure			
				12		No exposure			
				13		No exposure			
				14		No exposure			
				15		No exposure			
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